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(71) Applicant (*for all designated States except US*): KETO-CYTONYX INC. [US/US]; Five Tower Bridge, 300 Barr Harbor Drive, West Conshohocken, PA 19428-2998 (US).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): GROSS, Richard, A. [US/US]; Department of Chemistry and Chemical Engineering, Polytechnic University, Six Metrotech Center, Brooklyn, NY 11201 (US).

(74) Agent: MITCHARD, Leonard, C.; Nixon & Vanderhye P.C., 901 North Glebe Road, 11th Floor, Arlington, VA 22203-1808 (US).

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(54) Title: OLIGOMERIC COMPOUNDS

(57) **Abstract:** A method is provided for the synthesis of a compound of general formula $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R wherein n is an integer of 3 to 10, A is the residue of a dihydsic alcohol and R is H, C_{1-4} alkyl or $H(OCH[CH_3]CH_2C[O])_n$- comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 10 (R)-3-hydroxybutyrate moieties with a dihydric alcohol in an organic solvent in the presence of a lipase. Preferably the method provides 1,3-butandiol ester mono- and di-adducts of tri-(R)-3-hydroxybutyrate oligomers, which have been produceable in pure form and not isolated previously. Also, the method provides for the synthesis of oligomeric ester mixtures of (R)-3-hydroxybutyrate by the acidified hydrolysis of poly(3-hydroxybutyrate) in the presence of 1,3-butandiol and 1,2-dichloroethane. Such esters have utility in producing ketogenesis, for both physiological and medical purposes. These oligomers are bioavailable when administered by either the oral or intravenous route and can, therefore, be used acutely or chronically to evoke ketogenesis to prevent cytotoxic damage to the organs of the body, and to treat or prevent, particularly by sustainable ketogenesis, a variety of medical conditions of the peripheral organs and brain, including psychiatric and neurological diseases.

OLIGOMERIC COMPOUNDS.

The present invention relates to novel oligomeric compounds that have utility as nutraceuticals and/or as medicaments for producing ketosis in humans and animals for nutraceutical or therapeutic purposes.

It is known that ketone bodies, particularly (R)-3-hydroxybutyrate (D-β-hydroxybutyrate) and acetoacetate, have both nutritional and therapeutic applications in man and many species of animals. US 6,136,862 and US 6,232,345 (incorporated herein by reference) relate to the use of D-β-hydroxybutyrate, oligomers, esters and salts thereof, *inter alia*, in the treatment of cerebral edema and cerebral infarction. US 6,207,856 and PCT/US99/21015 also refer to β-hydroxybutyrate and its oligomers, esters and salts thereof in protecting against other forms of neurodegeneration *inter alia*, through their proposed ability to activate the tricarboxylic acid (TCA) cycle and, through favourable redox reactions in cells and antioxidant activity, scavenge free radicals. β-Hydroxybutyrate has also been demonstrated to have cardioprotectant effect and can increase cardiac efficiency (Sato et al, FASEB J, 9: 651-658, 1995).

It is also known, based on studies of the EEG power spectra measured in freely-moving rats, that D-β-hydroxybutyrate and the induction of ketosis have therapeutic utility in the treatment of conditions including, but not limited to, affective and related psychiatric disorders, which include depression, anxiety, schizo-affective disorder, obsessive-compulsive disorder, panic disorder, social anxiety disorder, generalized anxiety disorder and post-traumatic stress disorder, impaired cognitive function and pain (Copending PCT/GB2005/01835); also in providing symptomatic relief in the treatment of Parkinson's Disease (PD) and other CNS disorders resulting from dopamine deficiency in the brain and also treating and preventing attention deficit hyperactivity disorder (ADHD) and related CNS disorders of cognition, impulsiveness, attention and aggression in children, adolescents and adults (Copending US Provisional Applications 60/611301 and 60/611302).

US6,207,856, US6,136,862, US6,207,856 and PCT/US99/21015, incorporated herein by reference, teach that preferred ketogenic precursors for producing such ketosis are monohydric-, dihydric and trihydric alcoholic esters of (R)-3-hydroxybutyrate, but

particularly a (R)-3-hydroxybutyryl ester of (R)-1,3-butandiol, more preferably the diester formed from two molecules of (R)-3-hydroxybutyrate and one molecule of (R)-1,3-butandiol.

However, it is also known that production of oligomers of (R)-3-hydroxybutyrate in pure form is problematic. PCT/US99/21015 exemplifies a ketogenic oligomer with a mixture of (R)-3-hydroxybutyrate trimer, tetramer and pentamer and exemplifies esters thereof with acetoacetyl trimer, tetramer and pentamer of (R)-3-hydroxybutyrate. Similarly, Hiraide et al (1999) J. Parenteral and Enteral Nutrition Vol 23. No 6 discloses the use of a mixture of dimer and trimer of (R)-3-hydroxybutyrate for studies performed to determine the ability of plasma to degrade these molecules to the monomer, (R)-3-hydroxybutyrate.

In order to ensure that previously untested material is safe and appropriate for human administration, by any route, it is first necessary to evaluate all of its significant components for toxicity and efficacy. In the case of multi-component materials, it is, therefore, necessary to evaluate each one of the components in a variety of toxicology and efficacy tests. Such tasks can be extremely expensive and time-consuming, and inevitably, this will be an important factor in any decision on whether or not to proceed with any particular assessment. Furthermore, a mixture of different components may need to be produced in a set ratio for its safety and efficacy evaluation to be valid.

The present invention provides various, single component oligomeric ketogenic compounds, which are suitable for use in animals and man for therapeutic and/or nutraceutical purposes.

In a first aspect of the present invention, there is provided a method for the synthesis of a compound of general formula $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R, wherein n is an integer of 3 to 10, -A- is the residue of a dihydric alcohol and R is H, C_{1-4} alkyl or $H(OCH[CH_3]CH_2C[O])_n$- comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 10 (R)-3-hydroxybutyrate moieties with a dihydric alcohol in an organic solvent in the presence of a lipase.

Preferably the method is for the synthesis of a compound of general formula $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R, wherein n is an integer of 3 to 5, -A- is the residue of a 1,3 alkyl diol and R is H or $H(OCH[CH_3]CH_2C[O])_n$- comprising reacting a cyclic

oligomer of (R)-3-hydroxybutyrate containing between 3 and 5 (R)-3-hydroxybutyrate moieties with a 1,3-alkyl diol in a furan or pyran solvent in the presence of a lipase.

Still more preferably, the method is that wherein n is 3, -A- is a 1,3-butandiol residue, R is H, the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 1,3-butandiol, the solvent is tetrahydrofuran (THF) and the lipase is Candida antarctica lipase type B (CAL-B), particularly that available from Novozyme as Novozyme 435.

By the term 'residue of a dihydric alcohol' is intended the moiety remaining after the alcohol is diesterified not including the alcoholic oxygens, thus the residue of 1,3,-butandiol will be the group CH_3-(CH-)-CH_2-CH2-, with the residue being connected to the rest of the molecule at directly through its 1 and 3 carbons.

Preferably the method is that wherein the 1,3-butandiol is racemic and in one preferred form of that method the product provided is at least 95% mono-adduct wherein R is H.

A further preferred method is that wherein n is 3, A is a 1,3-butandiol residue, R is $H(OCH[CH_3]CH_2C[O])_3$- , the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 1,3-butandiol, the solvent is tetrahydrofuran and the lipase is CAL-B, particularly that wherein the alcohol is (R)-1,3-butandiol. Again, the method is preferably that wherein the enzyme is Novozyme 435.

Still more preferably n is 3, A is a 1,3-butandiol residue, R is $H(OCH[CH_3]CH_2C[O])_3$- , the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is (R)-1,3-butandiol , the solvent is a mixture of tetrahydrofuran and toluene in ratio in the range 10:90 to 90:10 and the lipase is CAL-B.

For such method the product is a mixture of mono and di-adducts of $H(OCH[CH_3]CH_2C[O])_3$- with (R)-1,3-butandiol in ratio of 10:90 to 90:10.

In a convenient embodiment of the invention, the products are separated and purified by column chromatography using a methanol:chloroform mixture. More preferably the mixture is between 1 and 5% methanol and 99 to 95% chloroform v/v.

Cyclic esters of (R)-3-hydroxybutyrate are known in the art and are readily produced by known methods: see for example Seebach et al. Helvetia Chimica Acta Vol 71 (1988) pages 155-167, and Seebach et al. Helvetia Chimica Acta, Vol 77 (1994) pages 2007 to 2033.

In a second aspect, the present invention provides novel esters of (R)-3-hydroxybutyrate having efficacy in raising ketone body levels on adminstration to humans and animals, particularly, but not exclusively, by the oral, parenteral or intravenous route.

Preferred compounds of the second aspect are compounds of formula I $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R wherein n is an integer of 3 to 5, A is a residue of an 1,3 alkyl diol and R is H or $H(OCH[CH_3]CH_2C[O])_n$-.

Preferably n is an integer of 3 to 5 and A is the residue of (R)-1,3-butandiol, more preferably (R)-1,3-butandiol.

More preferably n is an integer 3, 4, 5 and A is the residue of (R)-1,3-butandiol.

One particular group of diesters of (R)-1,3-butandiol with said oligomers are those wherein both of the two oligomer components of the ester are identical. Most conveniently the compounds of the second aspect of the present invention are diesters of one equivalent of (R)-1,3-butandiol with two equivalents of the trimer of (R)-3-hydroxybutyrate. These compounds have advantage in that all of the component alcohol and acid moieties are converted to energy producing elements in the body on administration.

In a third aspect of the invention, there is provided a compound of the second aspect of the invention in a substantially pure form, preferably containing no more than 10% by weight, more preferably no more than 5% by weight, of other (R)-3-hydroxybutyrate moiety containing compounds.

Particularly this aspect provides a compound of the second aspect in at in least 90% weight/weight pure form, more preferably at least 95% w/w form. More particularly at least 98% w/w form

In a fourth aspect of the invention, there is provided a nutraceutical or pharmaceutical composition comprising a compound of the first aspect together with a foodstuff component or a pharmaceutically acceptable carrier, diluent or excipient. Such foodstuff components may be selected for example from the common food groups such as carbohydrates, proteins, fats and vitamins. Carbohydrates may for example be selected from mono-, oligo- and polysaccharides or may even be alternative mono-, oligo- and polymeric forms of (R)-3-hydroxybutyrate.

In a fifth aspect of the present invention is provided the use of a compound of the first aspect of the present invention for the manufacture of a medicament for producing a physiologically acceptable ketosis. Such medicament will be suitable for treating a number of debilitating conditions that will benefit from the induction of ketosis. These include, but are not limited to, damage to the major organs such as occurring during hemorrhage, myocardial infarction, congestive heart failure, pulmonary infarction, kidney failure, where the medicament may be administered via the appropriate clinical route, which includes, but is not limited to, oral and intravenous.

Where the medicament is intended to be given intravenously, the compounds of the invention may be formulated as solutions. The present compounds have advantage that many of them are water soluble and do not require counterions, such as the sodium, potassium or calcium that is conventional with molecules such as the (R)-3-hydroxybutyrate monomer, acetate or lactate.

Particularly suitable carriers, diluents and excipients which may be utilised for eg. oral and parenteral, formulations, may be selected from conventional options such as those disclosed in the patents listed herein, or in Remington, *The Science and Practice of Pharmacy* 21st Edition, Edit David B Troy ISBN 0-7817-4673-6. for example, see Chapter 39 for Solutions. Emulsions, Suspensions, Syrups, Elixirs and Extracts. For example, Elixirs are clear, optionally flavoured liquids for oral use.

The compounds may also be used for the treatment of neurological and psychiatric conditions, such as stroke, head trauma, neurodegenerative conditions, including Alzheimer's and Parkinson's diseases, epilepsy, pain, spasticity and related motor disorders, affective and related psychiatric disorders, including depression, anxiety, schizo-affective disorder, obsessive-compulsive disorder, panic disorder, social anxiety disorder, generalized anxiety disorder and post-traumatic stress disorder, attention deficit hyperactivity disorder (ADHD) and related CNS disorders of cognition, impulsiveness, attention and aggression, diabetes, and obesity. These compounds can also be used to prevent cytotoxic damage to all end-organ systems, including, but not limited to, the central nervous system including its associated sensory, motor, cognitive and emotional function, heart, lung, liver, kidney and gut, such as occurring during major surgery.

The present invention will now be described further by reference to the following non-limiting Examples, Schemes and Figures. Further embodiments falling within the scope of the claim will occur to those skilled in the art in the light of these.

FIGURES

Figure 1: shows the reaction scheme for synthesis of the triolide of (R)-2-hydroxybutyrate.

Figure 2: shows the reaction scheme for synthesis of the mono-adduct (KTX0202).

Figure 3: shows the reaction scheme for synthesis of the mono-adduct and di-adduct KTX0202 and 0203.

Figure 4: shows ketogenic effect of oral administration KTX 0101 (sodium β-hydroxybutyrate) as determined by increases of β-hydroxybutyrate concentrations in rat plasma. Animals were dosed with KTX 0101 (300mg/kg po) and killed at the relevant time-points for collection of plasma. Samples were assayed with the standard Ranbut assay using a 20μl sample volume and values are shown as mean ± SEM, n=4. One-way analysis of variance followed by Dunnett's test was used to compare post-dose time-points to the baseline (T=0) control; ***$P<0.001$, *$P<0.05$.

Figure 5: shows ketogenic effect of oral administration of the mono-adduct (KTX 0202) as determined by increases of β-hydroxybutyrate concentrations in rat plasma. Animals were dosed with KTX 0202 (300mg/kg po) and groups (n=4) were killed at 30, 120 and 240 minutes for collection of plasma. Terminal cardiac plasma samples were also taken at baseline (T=0). Samples were assayed using the Ranbut β-hydroxybutyrate spectrophotometric assay with a 20μl sample volume. Values are shown as mean ± SEM, n=4. One-way analysis of variance followed by Dunnett's test was used to compare post-dose time-points to the baseline (T=0) control; ***$P<0.001$, *$P<0.05$.

Figure 6: Ketogenic effect of oral administration of the di-adduct (KTX 0203) as determined by increases of hydroxybutyrate concentrations in rat plasma. Animals were dosed with KTX 0203 (300mg/kg po) and groups (n=4) were killed at 30, 120 and 240 minutes for collection of plasma. Terminal cardiac plasma samples were also taken at baseline (T=0). Samples were assayed using the Ranbut β-hydroxybutyrate spectrophotometric assay with a 20μl sample volume. Values are shown as mean ± SEM, n=4. One-way analysis of variance followed by Dunnett's test was used to compare post-dose time-points to the baseline (T=0) control; ***P<0.001.

Figure 7: Shows ketogenic effect of oral administration of the (R)-3-β-hydroxybutyrate triolide as determined by increases of plasma hydroxybutyrate concentrations in rat plasma. Animals were dosed and groups (n=6) killed at the indicated time-points for collection of whole blood and subsequent collection of plasma. Samples were assayed using the Ranbut spectrophotometric assay described (20μl sample size) and individual values are the mean of triplicate determinations. Group means are shown as ± SEM, n=6. Statistical comparisons against baseline (t=0) were by multiple t-tests (***p<0.001).

Figure 8: Shows ketogenic effect of intravenous injection of the mono-adduct (KTX 0202) as determined by increases of plasma hydroxybutyrate concentrations in rat plasma. Animals were dosed with an intravenous bolus and groups (n=6) killed 15 minutes later for the collection of whole blood and subsequent collection of plasma. Samples were assayed with the Ranbut spectrophotometric assays (20μl sample size) and individual values are the mean of triplicate determinations. Group means are shown as ± SEM, n=6. Statistical comparisons against baseline (t=0) were by multiple t-tests (***p<0.001).

EXAMPLES

General procedure for the synthesis of R-3-hydroxybutyrate triolide from PHB [poly(3-hydroxybutyrate)] (Figure 1)

A mixture of poly(3-hydroxybutyrate) (PHB; 36g) and toluene-4-sulphonic acid monohydrate (23g) in 750 ml of toluene/dichloroethane (4:1) was heated and stirred at

reflux for 20hrs. The water was removed azeotropically using a Dean-Stark trap for 15 hrs. The resulting clear brown solution was cooled to room temperature, washed with a half-saturated solution of Na_2CO_3, then washed with a saturated solution of NaCl, dried over $MgSO_4$, filtered and evaporated to dryness. The crude mixture was purified by column chromatography using silica gel as the stationary phase and a hexane/ethylacetate mixture as the eluent followed by repeated crystallizations. The yield of the purified product was 15g (40%).

Analysis of the product was as follows: ***melting point*** 110°C; ***^{1}H NMR (300 MHz, $CDCl_3$)***: δ 1.30 (9H, d,J=6.4 Hz, CH_3), 2.39 (3H, dd, J=2.1, 11.3 Hz), 2.46 (3H, dd, J=11.3, 13.5Hz) and 5.31-5.39 (3H, m, CH); ***^{13}C NMR (75.5 MHz, $CDCl_3$)***: δ 20.76 (CH_3), 42.16 (CH_2), 68.87 (CH) and 170.01 (CO).

LIPASE CATALYZED TRANS-ESTERIFICATION PROCESS:

EXAMPLE 1: Synthesis of 1-(tri(R)-3-hydroxybutyryl-butane-1,3-diol) ester (KTX0202)

The enzyme-catalyzed ring-opening of the (R)-3-hydroxybutyrate triolide (cyclic trimer ester) with racemic 1,3--butandiol was studied as a function of the lipase source, reaction temperature, solvent, and time. The results of this work are given in Table 1.

Into a round-bottom flask (50 ml) was added purified triolide (100 mg, 0.387 mmol), (R,S)-1,3-butandiol (69.8 mg, 0.774 mmol), 1 ml of anhydrous organic solvent, and lipase (34 mg, 20%-by-wt relative to total substrates). The reactions were performed at selected reaction temperatures and times (Table 1). The reactions were terminated by first cooling the reaction mixture to room temperature, removing the enzyme by filtration, and then stripping the solvent by rotary-evaporation. A total of 525 reactions were carried out.

TABLE 1:

Enzyme	Solvent (1)	Temperature (°C)	Time (hr)	Result
Candida cylindrecea lipase (CCL)	1 to 5	1 to 5	1 to 3	Negative
Porcine pancreatic lipase (PPL)	1 to 5	1 to 5	1 to 3	Negative
Amano pseudomonas cepecia (PS)	1 to 5	1 to 5	1 to 3	Negative
Candida antarctica lipase (CAL-B)	1 to 5	1 to 5	1 to 3	Positive in one solvent
Mucor meihei	1 to 5	1 to 5	1 to 3	Negative
Lipase pseudomonas fluorescence (PF)	1 to 5	1 to 5	1 to 3	Negative

Solvents: (1) tetrahydrofuran (THF) (2) toluene, (3) acetonitrile, (4) dioxane and (5) diethyl ether. ***Temperatures***: (1) 45, (2) 50, (3) 55, (4) 60 and (4) 70°C. ***Reaction times***: (1) 24, (2) 48, (3) 72 hrs.

CAL-B in THF at 55°C was the best system for carrying out this reaction. No other lipase was found to be active. The product was purified by column chromatography using silica gel as the stationary phase and MeOH/$CHCl_3$, 2% v/v as the eluent. Analysis of the product was as follows:

Yield: 61% (82 mg) of a transparent oil; ***IR ($CHCl_3$) cm^{-1} :*** 3447, 2926,1750, 1392 and 1197; ***^1H NMR (300 MHz, $CDCl_3$):*** δ 1.20 (12H,d,J= 6.4Hz, CH_3), 1.70-1.78 (4H,m,H-3,$COCH_2$), 2.38-2.46 (4H,m,COCH_2×2), 3.11(1H,brs,OH exchangeable with D_2O), 3.88-3.95(1H,m,CH), 4.16-4.21 (3H,m,OCH_a,2XCH), 4.31-4.38 (1H,m,CH_b) and 5.13-5.34(1H,m,CH); ***^{13}C NMR ($CDCl_3$):*** δ 20.81,22.92 (CH_3), 38.17(C-3),43.68($COCH_2$×3), 62.48(C-4), 64.66(C- 2), 65.49(CH) and 173.41 (CO); ***MS (FAB, 3-NBA) $[M]^+$(% int):*** 349.23[$(M+H)^+$,13], 307.13(26), 289.11(18), 263.17(18), 219.20(8), 177.13(48), 154.06(100) and 137.05(77).

Thus, this is consistent with the mono-(tri-(R)-3-hydroxybutyrate) adduct, being metabolically equivalent to four units of (R)-3-hydroxybutyrate. In the examples below the mono-adduct is referred to as tetramer, containing three (R)-3-hydroxybutyrate moieties and one butandiol-providing four metabolic equivalents of (R)-3-hydroxybutyrate on metabolism. Similarly the di-adduct is referred to as the heptamer, having six (R)-3-hydroxybutyrate moieties and one butandiol.

EXAMPLE 2: Synthesis of 1-(tri(R)-3-hydroxybutyryl-butane-1,3-diol (KTX 0202; tetramer) (Figures 2 and 3) and of 1-3 butandiol, di-(tri(R)-3-hydroxybutyryate) ester (KTX 0203; heptamer) (Figure 3)

After successfully completing the ring-opening of triolide using (R,S)-1,3-butandiol, the reaction was repeated as above (CAL-B, in THF, 72 hrs, 55°C) except that (R)-1,3-butandiol was used in place of its racemate. Thus, into a round-bottom flask (50 ml) was added purified triolide (100 mg, 0.387 mmol), (R)-1,3-butandiol (69.8 mg, 0.774 mmol), 1 ml of an anhydrous organic solvent, and CAL-B (34 mg, 20%-by-wt relative to total substrates). Unexpectedly, in addition to the tetramer that was the primary product using racemic butandiol, the corresponding heptamer was found as a co-product. These two products were separated by column chromatography ($MeOH/CHCl_3$, 2:98 v/v). The structure of tetrameric product was confirmed as follows:

Yield: 42% (56 mg) of a transparent oil; ***^1H NMR (300 MHz, $CDCl_3$):*** δ 1.20 (12H,4d,J= 6.4Hz, CH_3), 1.70-1.83(4H,m,H-3,$COCH_2$), 2.41-2.53 (4H,m,$COCH_2$×2), 3.42, 3.69 (2H,brs,OH exchangeable with D_2O), 4.19-4.24(1H,m,CH), 4.29-4.38 (3H,m,OCH_a,2XCH),4.40-4.45(1H,m,CH_b) and 5.12-5.18(1H,m,CH); ***^{13}C NMR (75 MHz, $CDCl_3$):*** δ 22.63,23.55 (CH_3), 37.68(C-3),43.23(C-6,C-10,C-14), 62.11(C-2,C-15), 64.29(C-7,C-11), 64.89(C-4) and 172.91 (CO); ***CHN Analysis:*** Anal. Calcd for $C_{16}H_{28}O_8$: C, 55.16; H, 8.10; O, 36.74.Found: C, 54.03; H, 8.85; O, 37.12.

EXAMPLE 3: Synthesis of 1-(tri(R)-3-hydroxybutyryl-butane-1,3-diol (KTX 0202; tetramer) (Figures 2 and 3) and of 1,3 butandiol, di-(tri(R)-3-hydroxybutyryate) ester (KTX 0203; heptamer) (Figure 3)

The structure of heptamer product was confirmed as follows: **Yield:** 35% (82mg) of a transparent oil; *[1]H NMR (300 MHz, $CDCl_3$):* δ 1.24-1.30 (21H,m, CH_3), 1.87-1.93 (4H,m,H-17,2X$COCH_2$), 2.38-2.63 (14H,m,$COCH_2\times7$), 2.96- 3.09(1H,m,OH), 4.11-4.19 (7H,m,5XCH,OCH_2), and 5.09- 5.34(2H,m, 2 XCH); *[13]C NMR (75.0 MHz, $CDCl_3$):* δ 19.82, 22.61,23.49 (CH_3), 37.80,38.80,40.83,43.44, 62.11 (CH_2), 64.40,64.52,67.52,67.88,68.82(CH), and 169.59,170.72,170.47,171.88 (CO). ***CHN Analysis:*** Anal. Calcd for $C_{28}H_{46}O_{13}$: C, 56.94; H, 7.85; O, 35.21. Found: C, 54.26; H, 8.28; O, 37.46.

The ratio of the mono to di-adduct produced in the reaction mixture before separation could be altered by solvent changing. Thus by using a 1:1 mixture v:v of THF to toluene, the ratio of mono:di was changed to 2:3, the reaction being monitored using LC:MS. The formation of the heptamer might occur through the triolide ring opening by action of the tetramer. However, it is believed that repetitive transfer of butyrate units from one tetramer to another is the preferred reaction. Early in the reaction only one peak at 371.27 (M+Na) corresponding to the mono adduct was detected followed by transfer of trimer between molecules to give the di-adduct and some (R)-3-hydroxybutyrate monomer, which was subsequently removed in the purification step.

EXAMPLE 4: Ketogenic activity after oral administration of esters of the invention.

Male Sprague-Dawley rats (weight range 200-250g; Charles River, Margate, Kent) were used. The rats were group-housed in polypropylene cages at a temperature of 21±4°C, 55±20% humidity on a standard 12 hour light/dark cycle (lights on at 6.00am). Animals had free access to a standard pelleted rat diet and tap water at all times. Animals were acclimatized to these conditions for at least one week before experimentation.

The sodium salt of D-β-hydroxybutyrate monomer (KTX 0101) was used as a comparator for assessing the bioavailability of the oligomeric compounds described here.

KTX 0101 (Sigma 298360 Lot 18927HB), KTX 0202 or KTX 0203 were administered by oral gavage (po) at 300mg/kg. Control animals received the appropriate vehicle (deionized water at 1ml/kg) via the same route.

Protocol A: KTX 0101 only

Group	Number of animals	Time of blood sampling (min)	Treatment
3	4	0	Vehicle dosed
4	4	15	KTX 0101 (sodium D-β-hydroxybutyrate) 300mg/kg po
5	4	30	KTX 0101 300mg/kg po
6	4	60	KTX 0101 300mg/kg po

Protocol B: KTX 0202 and KTX 0203 only

Group	Number of animals	Time of blood sampling (min)	Treatment
A	4	0	Vehicle baseline
B	4	30	KTX 0202 300mg/kg po or KTX 0203 300mg/kg po
C	4	120	KTX 0202 300mg/kg po or KTX 0203 300mg/kg po
D	4	240	KTS 0202 300mg/kg po or KTX 0203 300mg/kg po

Protocol E: (R)-3-β-hydroxybutyrate triolide only

Group	Number of animals	Time of blood sampling (min)	Treatment
A	6	0	Vehicle baseline
B	6	60	(R)-3-β-hydroxybutyrate triolide 300mg/kg po
C	6	120	(R)-3-β-hydroxybutyrate triolide 300mg/kg po

In Protocol A, blood (approx 10 ml) was collected by cardiac puncture at 15, 30 and 60 minutes after dosing. In Protocol B, blood (approx 5 ml) was collected by cardiac puncture at 30, 120 and 240 minutes after dosing. In Protocol E, blood (approx 5 ml) was collected by cardiac puncture at 120 and 240 minutes after dosing. Animals were killed by CO_2 asphyxiation and blood collected by cardiac puncture. Blood was placed into EDTA-coated plasma collection tubes (Sarstedt 5 ml K2E tubes) and kept on ice prior to centrifugation. Tubes were centrifuged in an Eppendorf 570R centrifuge at 4°C for 5 minutes at 2500rpm (1000g). Plasma samples were initially frozen on dry ice and transferred to a -75°C freezer until required for analysis.

Commercial clinical assay kits (Ranbut) for the determination of D-β-hydroxybutyrate were obtained from Randox Laboratories (Antrim, UK). The kit quantified NADH via the activity of β-hydroxybutyrate dehydrogenase measured as an increase in OD340nm. An alkaline pH is necessary to drive the reaction equilibrium towards the production of NADH and acetoacetate.

$$\text{Hydroxybutyrate} + NAD^+ \underset{\text{pH 7.0}}{\overset{\text{pH 8.5}}{\rightleftharpoons}} \text{NADH} + \text{Acetoacetate}$$

This spectrophotometric assay was modified for application to a 96-well microplate format. The reaction rate was then determined from the increase in OD340nm over a 1 minute time-course, after allowing a necessary period for the reaction rate to settle.

KTX 0101 (sodium β-hydroxybutyrate): After oral administration at 300 mg/kg, the sodium salt of the monomer rapidly increased plasma concentrations of β-hydroxybutyrate (Figure 5). The maximum increase was 0.4mM observed at 15 min ($P<0.001$), it plateaued0 at this level until 30 min ($P<0.001$) and declined thereafter. The level β-hydroxybutyrate was still significantly ($P<0.05$) elevated at 1 h, but it returned to control values by 2 h.

KTX 0202 (mono-adduct): After oral administration at 300 mg/kg, the tetramer also significantly increased plasma concentrations of β-hydroxybutyrate (Figure 6). The maximum increase was 0.4 mM observed at 30 min ($P<0.001$); it declined thereafter, but was still significantly ($P<0.05$) elevated at 2 h. Plasma β-hydroxybutyrate levels returned to control values by 4 h.

KTX 0203 (di-adduct): After oral administration at 300 mg/kg, the heptamer also significantly increased plasma concentrations of β-hydroxybutyrate (Figure 7). The maximum increase was 0.4mM observed at 30 min ($P<0.001$); it declined thereafter and plasma β-hydroxybutyrate levels returned to control values by 2 h.

(R)-3-β-hydroxybutyrate triolide: After oral administration at 300 mg/kg, the triolide significantly increased plasma concentrations of β-hydroxybutyrate (Figure 10). The maximum increase was 0.5 mM observed at 60 min ($P<0.001$); it declined thereafter, but was still significantly ($P<0.001$) elevated at 2 h.

EXAMPLE 5: Ketogenic activity after intravenous injection of esters of the invention.

Male Sprague-Dawley rats (weight range 200-250g) were obtained from Charles River, Margate, Kent. The rats were group housed in polypropylene cages at a temperature of 21±4°C, a humidity of 55±20% and on a standard light/dark cycle. Animals had free access to a standard pelleted rat diet and tap water at all times.

Animals were accustomed to these conditions for at least one week before experimentation.

KTX 0101 (synthesized by KetoCytonyx) was dissolved at 300mg/ml in deionized water which produced a clear solution of pH 7.0. Similarly, KTX 0202 was dissolved at 300mg/kg in deionized water and produced a slightly opaque solution with a pH of 6.0. The compounds were infused via the tail vein at 300mg/kg (1ml/kg) over a period of 1 to 2 min.

Groups for each of the above compounds:

Group	Number of animals	Time of blood sampling (min)	Treatment
A	6	15	Vehicle
B	6	15	KTX 0101
C	6	15	KTX 0202

Animals were killed 15 min later by CO_2^- asphyxiation and blood was collected by cardiac puncture. Blood was placed into EDTA-coated plasma collection tubes (Sarstedt 5 ml K2E tubes) and kept on ice prior to centrifugation. Tubes were centrifuged in an Eppendorf 570R centrifuge at 4°C for 5 minutes at 2500rpm (1000g). Plasma samples were initially frozen on dry ice and transferred to a -75°C freezer until required for analysis.

Commercial clinical assay kits (Ranbut) for the determination of D-β-hydroxybutyrate were obtained from Randox Laboratories (Antrim, UK). The kit quantified NADH via the activity of β-hydroxybutyrate dehydrogenase measured as an increase in OD340nm. An alkaline pH is necessary to drive the reaction equilibrium towards the production of NADH and acetoacetate.

$$\text{Hydroxybutyrate} + NAD^+ \underset{\text{pH 7.0}}{\overset{\text{pH 8.5}}{\rightleftharpoons}} \text{NADH} + \text{Acetoacetate}$$

KTX 0101 (sodium β-hydroxybutyrate): After intravenous injection at 300 mg/kg, the sodium salt of the monomer rapidly increased plasma concentrations of β-hydroxybutyrate (Figure 11). An increase to 1.0 mM was recorded at 15 min ($P<0.001$).

KTX 0202 (mono-adduct): After intravenous injection at 300 mg/kg, the tetramer also rapidly increased plasma concentrations of β-hydroxybutyrate (Figure 11). An increase to 1.7 mM was recorded at 15 min ($P<0.001$).

Discussion

These results demonstrate that KTX 0202 (mono-adduct, tetramer of (R)-3-β-hydroxybutyrate) and KTX 0203 (di-adduct, heptamer of β-hydroxybutyrate) are both orally bioavailable and are capable of producing ketosis when given to rats. The magnitude of the increases in plasma β-hydroxybutyrate evoked by KTX 0202 and KTX 0203 are at least as great as those produced by KTX 0101, the sodium salt of β-hydroxybutyrate. Moreover, in the case of KTX 0202, this β-hydroxybutyrate oligomer has an improved biological half-life relative to KTX 0101.

The (R)-3-β-hydroxybutyrate triolide was also able to increase plasma concentrations of β-hydroxybutyrate after being administered via the oral route, as disclosed in WO00/15216. Once again, the elevation of plasma β-hydroxybutyrate was at least as great as that evoked by oral administration of the equivalent dose of KTX 0101. Like KTX 0202, (R)-3-β-hydroxybutyrate triolide has an improved biological half-life relative to KTX 0101.

The results also demonstrate that KTX 0202 (mono-adduct, tetramer of (R)-3-β-hydroxybutyrate) is bioavailable when injected via the intravenous route of administration. When injected at identical doses, ie 300 mg/kg iv, KTX 0202 increased the plasma concentration of β-hydroxybutyrate at 15 min by 60% more than KTX 0101.

Together, these results report a route for the synthesis of the novel oligomers of (R)-β-hydroxybutyrate having advantage of being water soluble and defined for purposes of producing ketosis in subjects. The experimental data also demonstrate that these

compounds are biovailable when given by both the oral and intravenous routes of administration. Thus, these compounds will have utility as nutraceuticals, or as medicaments where they can be administered using clinically relevant routes, eg orally or intravenously.

CLAIMS.

1. A method for the synthesis of a compound of general formula $H(OCH[CH_3]CH_2C[O])_n\text{-}O\text{-}A\text{-}O\text{-}R$
wherein n is an integer of 3 to 10,
A is the residue of a dihydric alcohol
and R is H, C_{1-4} alkyl or $H(OCH[CH_3]CH_2C[O])_n$-

comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 10 (R)-3-hydroxybutyrate moieties with a dihydric alcohol in an organic solvent in the presence of a lipase.

2. A method for the synthesis of a compound of general formula $H(OCH[CH_3]CH_2C[O])_n\text{-}O\text{-}A\text{-}O\text{-}R$
wherein n is an integer of 3 to 5,
A is a residue of a 1,3 alkyl diol and
R is H or $H(OCH[CH_3]CH_2C[O])_n$-

comprising reacting a cyclic oligomer of (R)-3-hydroxybutyrate containing between 3 and 5 (R)-3-hydroxybutyrate moieties with a 1,3-alkyl diol in a furan or pyran solvent in the presence of a lipase.

3. A method as claimed in Claim 2 wherein n is 3, A is a 1,3-butandiol residue, R is H, the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 1,3-butandiol, the solvent is tetrahydrofuran and the lipase is CAL-B.

4. A method as claimed in Claim 3 wherein the 1,3-butandiol is racemic and the product is at least 95% mono-adduct with R being H.

5. A method as claimed in Claim 2 wherein n is 3, A is a 1,3-butandiol residue, R is $H(OCH[CH_3]CH_2C[O])_3$- , the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is 1,3-butandiol, the solvent is tetrahydrofuran and the lipase is CAL-B.

6. A method as claimed in Claim 5 wherein the alcohol is (R)-1,3-butandiol.

7. A method as claimed in Claim 2 wherein the enzyme is Novozyme 435.

8. A method as claimed in Claim 2 wherein n is 3, A is a 1,3-butandiol residue, R is $H(OCH[CH_3]CH_2C[O])_3$- , the cyclic oligomer is (R)-3-hydroxybutyrate triolide, the alcohol is (R)-1,3-butandiol, the solvent is a mixture of tetrahydrofuran and toluene in ratio in the range 10:90 to 90:10 and the lipase is CAL-B.

9. A method as claimed in Claim 8 wherein the product is a mixture of mono and di-adducts of $H(OCH[CH_3]CH_2C[O])_3$- with (R)-1,3-butandiol in ratio of 10:90 to 90:10.

10. A method as claimed in Claim 8 or 9 wherein the products are purified by column chromatography using a methanol:chloroform mixture.

11. A method as claimed in Claim 10 wherein the mixture is between 1 and 5% methanol and 99 to 95% chloroform v/v.

12. Isolated compound of formula $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R wherein n is an integer of 3 to 5, A is a residues of a 1,3 alkyl diol and R is H or $H(OCH[CH_3]CH_2C[O])_n$-. free of other oligomeric (R)-3-hydroxybutyrate moiety-containing compounds.

13. Isolated compound of formula $H(OCH[CH_3]CH_2C[O])_n$-O-A-O-R wherein A is $-CH_2(CH_3)CHCH_2$- of the (R)-optical form, free of other oligomeric (R)-3-hydroxybutyrate moiety-containing compounds.

14. 1-(tri(R)-3-hydroxybutyryl-butane-1,3-diol in substantially isolated form.

15. 1-3 butandiol, di-(tri(R)-3-hydroxybutyryate) in substantially isolated form.

16. A nutraceutical or pharmaceutical composition comprising a compound produced by a method as claimed in any one of Claims 1 to 11.

17. A nutraceutical or pharmaceutical composition comprising a compound as claimed in any one of Claims 12 to 16.

18. Use of a compound as provided in any one of claims 1 to 15 for the manufacture of a medicament for the production of therapeutic ketosis.

FIGURE 1

Scheme I. Synthesis of (R,R,R)-4,8,12-trimethyl-1,5,9-trioxadodeca-2,6,10-trione ([R]-3HB-triolide)

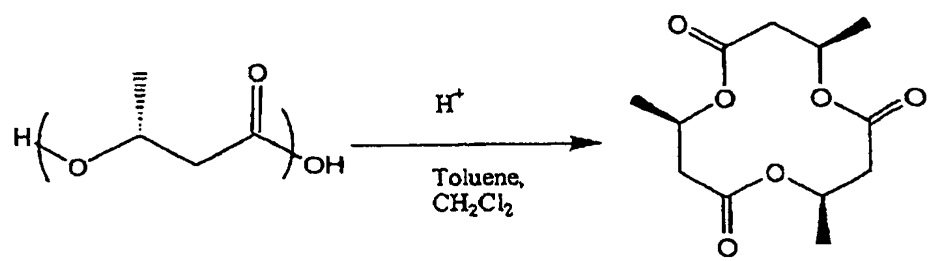


FIGURE 2

Production of the mono-adduct (KTX 0202)

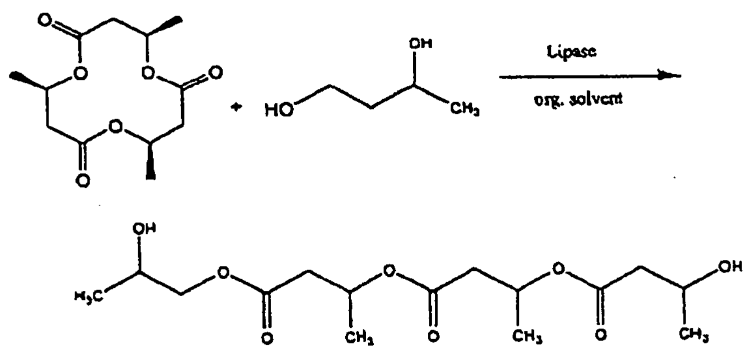


FIGURE 3

Production of mono-adduct (KTX 0202) and di- adduct (KTX 0203)

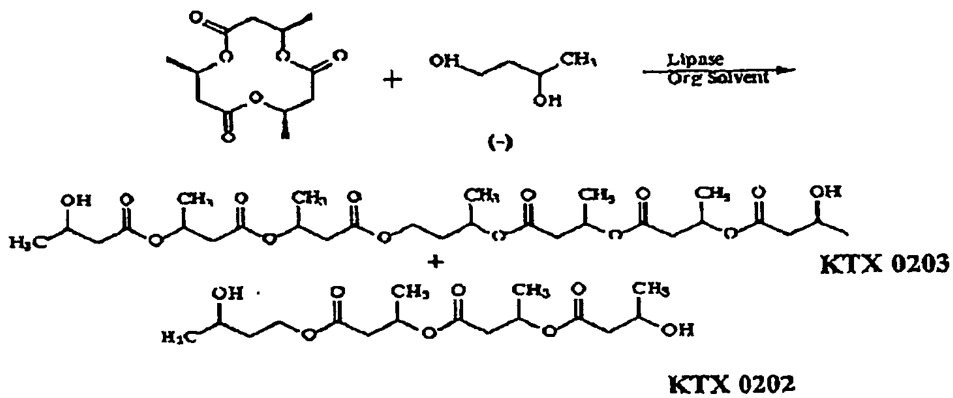


FIGURE 4

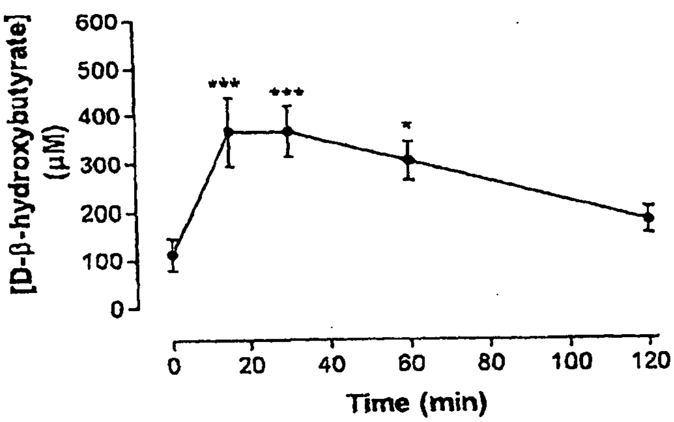

[D-β-hydroxybutyrate]
(μM)
600
500
400
300
200
100
0
***
***
*
0
20
40
60
80
100
120
Time (min)

FIGURE 5

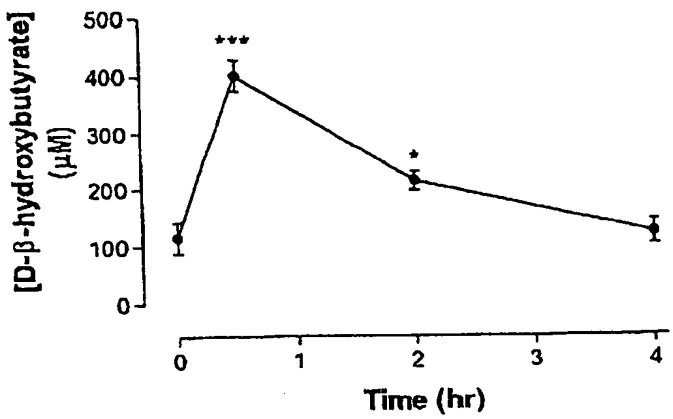


FIGURE 6

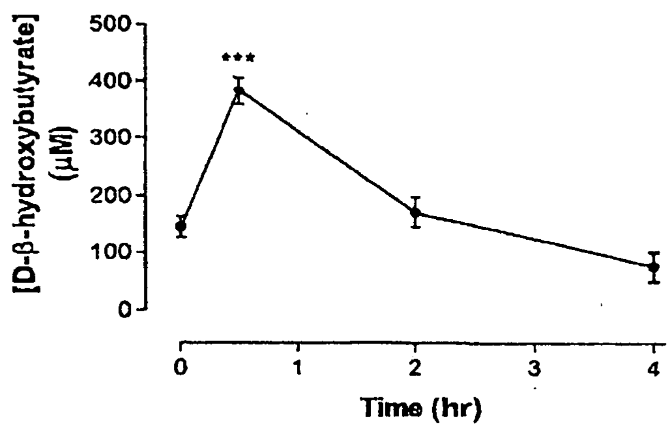


FIGURE 7

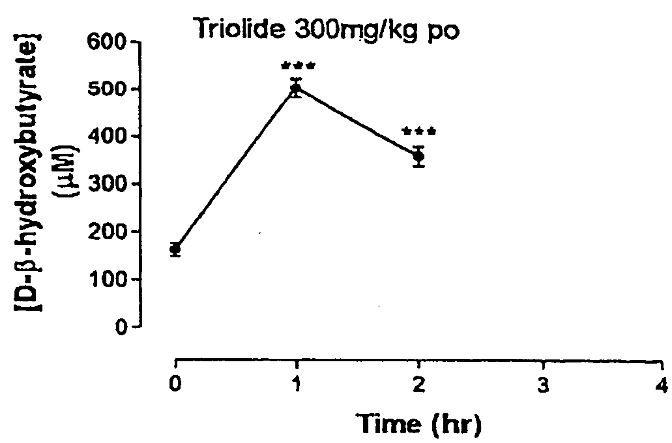
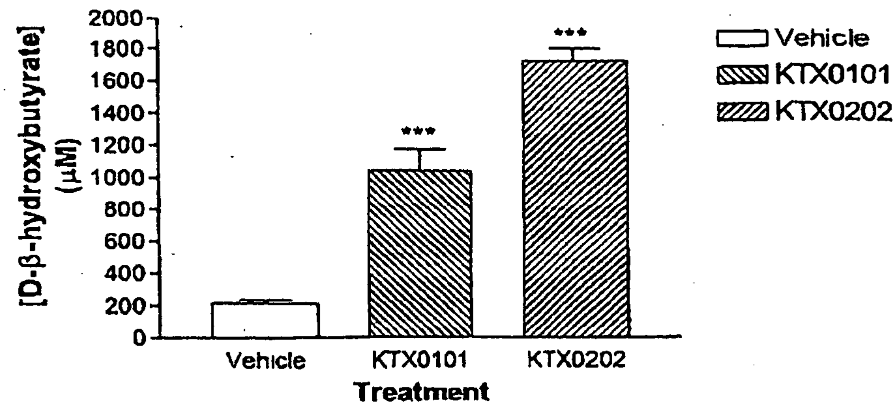

Triolide 300mg/kg po
[D-β-hydroxybutyrate]
(μM)
600
500
400
300
200
100
0
***
***
0
1
2
3
4
Time (hr)

FIGURE 8


[D-β-hydroxybutyrate] (μM)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
***
***
Vehicle
KTX0101
KTX0202
Treatment
Vehicle
KTX0101
KTX0202